UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

Project | Date | Author

TITLE

A STUDY OF MOUNTAIN PINE BEETLE INFESTATIONS IN WESTERN WHITE PINE

By
W. D. Bedard
Associate Entomologist

~~Annex 1~~
SB
763
I4 C6
1939

Forest Insect Laboratory
Coeur d'Alene, Idaho
February 23, 1939

U.S. GOVERNMENT PRINTING OFFICE 8—9742

SUBJECT—

INDEX NO.—

BUREAU OF Entomology and Plant Quarantine
RECEIVED
MAR 20 1939
FOREST INSECT LABORATORY,
PORTLAND, OREGON

File No. _____
Noted by JJ
RLF
WJO

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE
WASHINGTON, D. C.

March 15, 1939

Mr. J. C. Evenden
Coeur D'Alene
Idaho

Dear Evenden:

I have read Bedard's report "A Study of Mountain Pine Beetle Infestations in Western White Pine" transmitted with your letter of March 2, with a great deal of interest. I have always felt that these biological studies are extremely important, in that they may throw some light on the reasons for the fluctuation in bark beetle abundance and have some practical application in control.

Bedard has collected a great deal of information over the past three years, some of which is of undoubted significance and supports his interpretation. On other things, particularly the interrelation of various data, I am not so sure but that a more statistical analysis is necessary. It would be a good plan to put the past three years information on punch cards and run a multiple correlation on it. This should bring out the relative importance of certain factors which are now considered only on the basis of data pertaining to that particular factor.

Some of the general conclusions drawn by Bedard, I believe, are perfectly sound. Such things as the unfavorable effect of dry sites and small trees on brood development. This amply confirms our studies on the Kaibab. As you remember, Blackman pointed out that the extremely dry summer of 1924 had a remarkably unfavorable influence on survival, and our trap trees indicated that moist logs on the ground, particularly those covered with brush, produced tremendous broods. There also seems to be ample evidence to support the fact that the proportion of beneficial insects is much greater in small trees. It would be my suggestion that you apply this information the next few years in your control recommendations, avoding the treatment of all small trees and trees on the poor sites, and watch developments.

Another very significant factor brought out in this report seems to be the relation of growth to insect attack. The gradual decline in the rate of growth for the last century, may be of some significance and certainly the preponderance of attack in slow growing trees over the past 10 years appears to be so. Personally I am inclined to believe this factor may be of extreme weight and may offset many other things, such as the effect of beneficial insects. It might

be suggested here that some of these trees be studied again to determine the rate of growth for the past 2 or 3 years - that is just prior to attack and by cross identification of rings on attacked trees with nearby green trees, determine whether there are not some annual rings missing on the lower part of the stems.

This matter of tree vigor probably ties in very directly with the question of intensity of attacks. Could not the evidence be interpreted to mean that the variation of attacks per square foot over the past few years is an expression of tree vigor. That is, where there is a great abundance of weakened trees, the attacks would be fewer, while with a less abundance, there would be a greater concentration of beetles in those trees favorable for attack. Of course, this is known to be the case with wind-falls. If this interpretation is sound, you would have much the same situation in your infestations of the mountain pine beetle in white pine that they have with the western pine beetle in the East Side types of yellow pine in California.

I hope facilities are available for carrying this study on through another season or more. It might then be pushed less intensively until we get some change in general climatic or growth conditions and the study taken up again in the same detail. Of course, if facilities are available, it would be desirable to continue the work right through a long period of years.

Sincerely yours,

F. C. Craighead
In Charge
Forest Insect Investigations

fcc-es

BUREAU OF
Entomology and Plant Quarantine
RECEIVED
☆ MAR 4 - 1939 ☆
FOREST INSECT LABORATORY,
PORTLAND, OREGON

File No.
Noted by
RLF
WJB

Refer to file
Studies B-4A

Forest Insect Laboratory
Coeur d'Alene, Idaho
March 2, 1939

Dr. F. C. Craighead

Washington, D. C.

Dear Dr. Craighead:

There are enclosed two copies of a laboratory report by Mr. Bedard entitled "A Study of Mountain Pine Beetle Infestations in Western White Pine". One of these is for the files of your office and the other for circulation among the eastern stations or for any other distribution that you may desire. Reports on parasites and predators and the importance of different types of host material as shown by the infestation study have already been submitted. Another report concerning the application of this study to our survey data will be submitted in a few days.

Although we are pleased with the results that have been obtained from this study, as it is contributing toward a clearer understanding and solution of our mountain pine beetle problem in white pine, we wish that it were possible to continue it on a basis other than the present set-up. We have used CCC enrollees with the results that have been presented. However, with trained men it would be possible to extend this study into areas that we are now unable to reach, and to improve the quality of the data that are now being obtained.

I shall not attempt to comment upon the highlights of this report which Mr. Bedard has clearly summarized. We would appreciate your comments and suggestions concerning this study, as we are exceedingly desirous of taking advantage of all possible suggestions for improvements.

Respectfully yours,

JAMES C. EVENDEN
Senior Entomologist

Enclosures

cc to:
Mr. Miller
Mr. Keen
Dr. Beal

A STUDY OF MOUNTAIN PINE BEETLE INFESTATIONS IN WESTERN WHITE PINE

by
W. D. Bedard
Associate Entomologist

Forest Insect Laboratory
Coeur d'Alene, Idaho
February 23, 1939

A STUDY OF MOUNTAIN PINE BEETLE INFESTATIONS IN WESTERN WHITE PINE

- - - -

OBJECTIVE AND METHOD

This study has for its object to make a detailed investigation of mountain pine beetle infestations in western white pine to obtain a better understanding of the factors governing the behavior of these infestations in order to be able to predict their future trend. During the past three seasons the work has been restricted to the Coeur d'Alene National Forest, except for limited data which were secured from one area on the Kaniksu and one area on the Clearwater Forest. The project was begun with an intensive study of the Coeur d'Alene situation with the expectation that during subsequent years data will be secured from other forests as well, although detailed information from any infestation should result in a better understanding of all mountain pine beetle outbreaks in white pine and improve the basis for making control recommendations.

The study was begun early in June in 1936, early in May in 1937, and early in June in 1938, with a crew of CCC enrollees varying in number from five to eight. During the first two seasons, an experienced foreman was obtained to direct the work of the crew, but during 1938 no foreman could be obtained so that the writer acted as foreman throughout most of the season. Mr. T. T. Terrell of the Coeur d'Alene Laboratory also spent considerable time with the crew during all three seasons, when the writer was engaged with other projects.

CONTENTS

	Page
Objective and Method	1
General Comparison of 1935, 1936, and 1937 Infestations	8
Biotic Potential and Environmental Resistance	10
Brood Potential	11
Parent Adult Emergence	15
Mortality Factors	19
Favorable Factors	20
Effect of Various Factors on Mountain Pine Beetle Abundance	25
Period of Attack	26
Exposure	28
Site	29
Location	31
Tree Diameter	32
Beneficial Insects	34
Bark Thickness	36
Density of Attack	39
Practical Application of the Study	43
Summary	45

Figure 1. One of the samplers examining log. Note that the log has been marked on the end for the four cardinal directions.

During the first part of the work in 1936 each tree was examined at 10-foot intervals along the bole, starting at five feet. Later, however, the interval of sampling was extended to 20 feet when it was found that this could be done without altering the character of the data, so that examinations during most of 1936 and all of 1937 and 1938 were made at 5, 20, 40, 60 feet, etc., up to the height of infestation. The 5-foot sample was considered representative of the basal 10 feet of the bole, the 20-foot sample represented the next 20 feet, the 40-foot sample from 30 to 50 feet, etc. The last sample was taken at the midpoint between the top of the last 20-foot log and the height of infestation. At each point of examination one-half square foot of bark was removed from the north, east, south and west sides of the tree, and insect populations and their work were recorded for each half-square-foot sample.

Following each day's work, the total of each factor in every log was first determined. Then, in order to secure the tree average, the totals for each individual factor in each log were added together and their sum divided by the total bark surface of the tree. In this way the unequal bark surface represented by the individual samples was weighted and the variations represented by the individual samples were absorbed in the average, which is more representative of tree conditions as a whole. In addition to insect data, other factors were recorded for each tree such as, tree class, diameter and bark thickness at each sample, crown shape, rate of growth, presence or absence of wood rot and Armillaria, site, exposure, and total height.

Figure 2. Stump of examined tree excavated to determine amount of root rot injury.

Figure 3. Portion of crew at work. Two samplers, note taker and stump excavator. Sampling equipment, bull-pen, note book, carpenter's hatchet, club for driving hatchet, and cant hook shown in foreground. Butt chisel used for removing and scraping bark is being used by sampler.

During the 1938 season, a cooperative study was undertaken with the Northern Rocky Mountain Forest and Range Experiment Station and the Forestry College of the University of Idaho, to determine something of the incidence, importance and relation to insect epidemics of Armillaria mellea and associated root rots. A portion of this study was combined with the infestation study and one CCC enrollee spent his entire time excavating the roots of the trees felled for examination. After excavation the writer examined the roots and recorded the necessary data on a form devised by all of the cooperating agencies.

Throughout the project, trees which were attacked during the previous season as well as those infested during the current season were examined. The previous season's trees showed conditions very close to final emergence, while the current season's attacks gave information on potential brood, progressive mortality during development, etc. This is in accordance with the plan of the study to examine trees, first, during the season of attack to secure potentials, and second, during the season of emergence to secure final population figures.

In using CCC enrollees for this type of work, excellent cooperation was secured from the Forest Service in providing good men who took an interest in the study. In addition, arrangements were made whereby these men could be transferred from camp to camp in order to secure as widely distributed areas for sampling as possible. It is highly desirable, however, to use older, more experienced men for the study if sufficient regular funds were available. This would be advantageous both from the standpoint of character and amount of data secured as well as ability to sample desirable areas which cannot be reached with CCC crews.

Figure 4. Entire crew working on group of trees.

A word might be said in this introductory material concerning the handling and presentation of the data. The interrelation of so many of the factors makes it difficult to discuss the material in a logical sequence, thus necessitating reference not only to text which has preceded, but also to information which is to follow.

GENERAL COMPARISON OF 1935, 1936, and 1937 INFESTATIONS

Comparable data for three seasons are now available to indicate changes which occur during the course of a mountain pine beetle infestation in western white pine. All trees represented in table I were examined just prior to or at the time of emergence so that the data show final development for all factors. The trees have been recorded according to the season of attack; hence emergence from these trees occurred during the following season.

TABLE I
COMPARISON OF INFESTATION DURING 1935, 1936 and 1937

Year of att.	Trees	Bark surface	Inf. bark per tree	D. m. brood	Average per square foot: Par. atts	Par. emerg. holes	Egg gall.	Gall per att.	Para.	Pred.	Robber work*
	no.	sq.ft.	sq.ft.	no.	no.	no.	in.	in.	no.	no.	sq.in.
1935	133	25,327	190	7.7	8.5	5.7	100.4	11.8	4.7	2.4	14.3
1936	106	20,258	191	38.3	3.3	1.9	54.3	16.4	3.6	1.4	23.1
1937	56	15,159	270	24.0	3.5	3.7	75.7	21.6	1.7	0.8	26.9

* Robber work includes bark destroyed by secondary bark beetles, wood borers and woodpeckers.

In table I it is apparent that there has been a decided change in the mountain pine beetle infestation on the Coeur d'Alene National Forest. From the 1935 trees there were only 7.7 new adults emerging per square foot in 1936 as compared with 38.3 from the 1936 trees and 24.0 from the 1937 trees. With this low emergence in 1936, the beetles infested the same amount of bark surface per tree, thus reducing the number of infested trees from .184 per acre in 1935 to .053 in 1936. This reduction would have been even greater had the beetles attacked with the same intensity during both years. In 1936, however, there were fewer attacks per square foot so that the actual reduction in beetle population was much less apparent. The more abundant broods produced from the 1936 trees brought the 1937 infestation from .053 tree per acre to .121. Here again the increase would have been greater had not the beetles attacked larger trees with approximately the same intensity as in 1936. The 1938 trees examined indicate more numerous attacks and less infested bark per tree so that the increase in 1938 was from .121 tree per acre to .186.

It is also apparent that with the exception of robber work there was a decided reduction in 1936 among the beneficial agents effective in controlling the mountain pine beetle. The cause of this mortality is not known, although the logging of infested logs in the creek bottom of one area examined has undoubtedly helped to reduce the beneficial insects in this area.

Another interesting point to be noted in table I is the abundance of parent adult emergence holes in the 1937 trees. In the 1935 and 1936 trees, parent emergence is approximately two-thirds of the number of attacks, while in 1937 parent emergence holes are equal to the attacks. This will be discussed later in a section concerning adult emergence.

This general comparison has been made for the infestation as a whole and therefore is not applicable to specific areas, nor will the indicated increase or decrease apply to the actual change which occurred. These data have been discussed here merely to show the general trend. In a later section, under the "effect of various factors on mountain pine beetle abundance" each unit will be discussed separately, while in a separate report the possibility of predicting increases and decreases will be discussed.

BIOTIC POTENTIAL AND ENVIRONMENTAL RESISTANCE

Before giving detailed consideration to those specific factors which have influenced the Coeur d'Alene infestation during the past three years, it might be well to attempt a few general remarks concerning the maximum abundance which might be attained by the mountain pine beetle and a general discussion of those factors which favor future increases as well as those which cause mortality. Chapman has proposed the terms "biotic potential" and "environmental resistance" to designate the two opposing forces which are at work to regulate the abundance of any organism. Sweetman and Graham define biotic potential as "the

inherent ability of an organism to produce and survive, within a given time, and under optimum environmental conditions". It takes into account the number of young produced in each reproduction, the number of reproductions in a given period of time, the sex ratio of the species, and their general ability to survive under given pysical conditions. Environmental resistance on the other hand is the sum total of physical and biotic factors which tend to reduce the numbers of the organism.

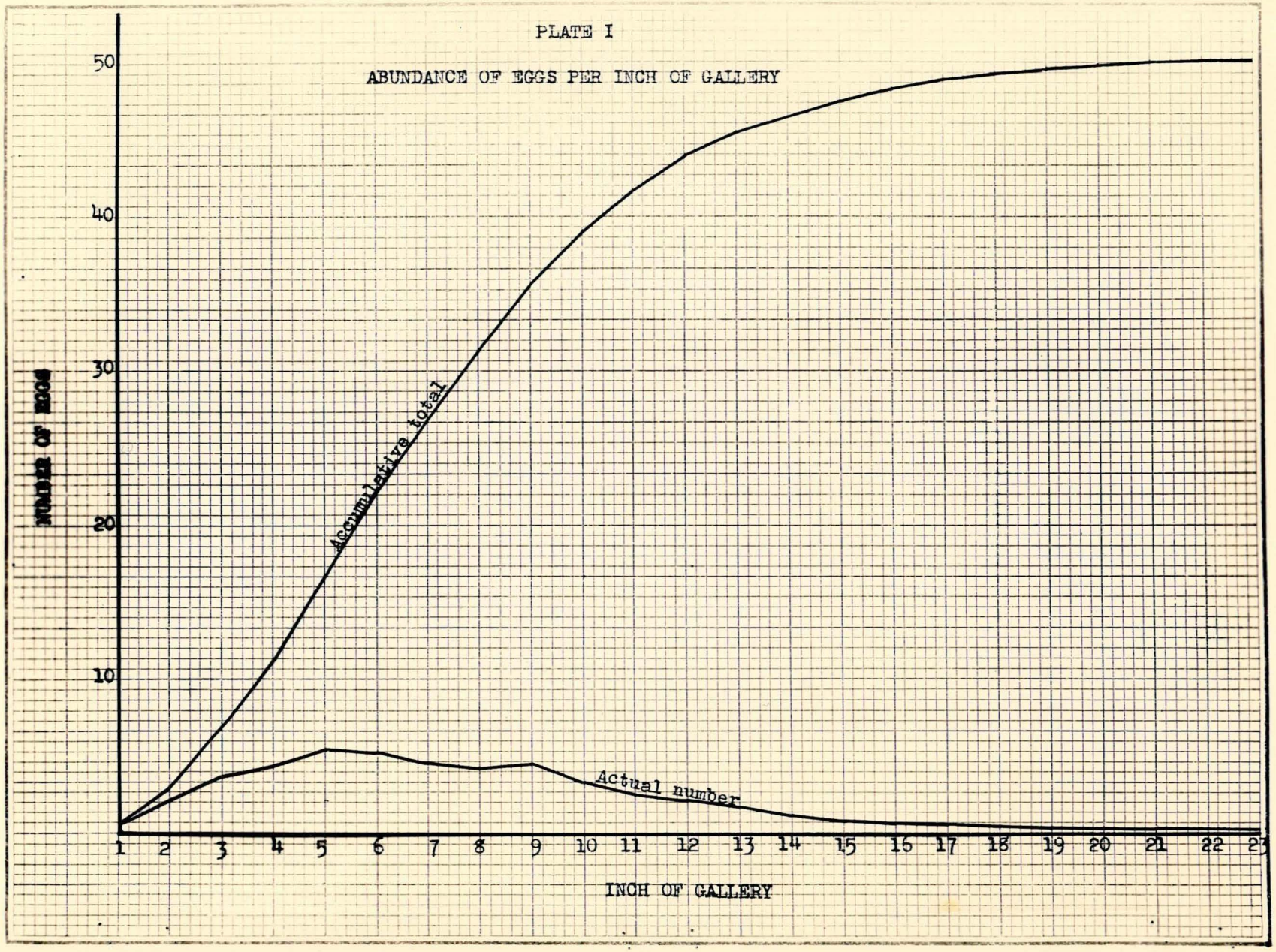
In the case of the mountain pine beetle the main physical factors are temperature and moisture; the principal biotic factors would include tree resistance, competition for food, plant and insect parasites, predatory arthropods, birds and mammals. With this conception in mind, the subjects of brood potential, parent adult emergence, factors causing mortality, and factors favoring development will be given general consideration followed by a section in which the effect of various factors is shown by the abundance of mountain pine beetle broods produced.

Brood Potential

A total of 494 egg galleries were examined during the three seasons to determine the number of eggs laid by each female beetle. In each case the eggs were recorded for each lineal inch of gallery as well as for the total length, so that it is possible to compute the number of eggs per beetle or the number of eggs per square foot

PLATE I

ABUNDANCE OF EGGS PER INCH OF GALLERY



of bark. In compiling these data for the three years of the study, their constancy was surprising. The various factors such as exposure, height along the bole, attack periods, etc., apparently have no effect on the number of eggs laid per inch of gallery, or per beetle. During the three seasons it was found that there was an average of approximately 50 eggs laid per gallery, or an average of 2.27 per inch in 1936, 2.18 per inch in 1937 and 2.21 in 1938. Naturally, these figures do not apply to specific galleries because of the range in length of gallery construction. Obviously, if only eight inches of gallery are constructed, the 50 eggs will be crowded closer together and average twice as high per inch than if the gallery were 16 inches long. As will be shown later, the mountain pine beetle usually emerges after making one attack and makes a second attack in another tree. In some cases, however, the female beetle remains in the same tree and deposits all of her eggs in one gallery, so that close to 100 eggs may be found in a single gallery. In table II the average number of eggs per inch of gallery is shown for 1936, 1937 and 1938.

TABLE II

AVERAGE DISTRIBUTION OF EGGS IN MOUNTAIN PINE BEETLE GALLERY

Year	Inch of gallery 1	2	3	4	5	6	7	8	9	10	11	12
1936	0.74	3.02	4.65	4.50	5.37	5.19	4.36	4.15	4.85	3.12	2.35	1.94
1937	0.38	1.17	2.87	4.15	6.16	5.61	5.30	4.47	4.31	3.56	2.98	2.62
1938	1.00	2.73	3.00	3.27	4.21	5.47	6.63	5.04	4.23	3.56	3.04	2.00
Three years	0.69	2.38	3.79	4.19	5.46	5.38	5.02	4.25	4.59	3.33	2.64	2.19

Year	Inch of gallery 13	14	15	16	17	18	19	20	21	22	23	Total
1936	1.37	1.01	0.87	0.67	0.54	0.50	0.35	0.25	0.13	0.12		50.05
1937	1.94	1.16	0.92	0.80	0.77	0.51	0.30	0.17	0.07	0.04	0.03	50.29
1938	1.48	1.10	0.88	0.74	0.58	0.51	0.30	0.25	0.10	0.07	0.00	50.19
Three years	1.58	1.07	0.90	0.72	0.64	0.51	0.33	0.22	0.10	0.09	0.01	50.08

In table II it is quite apparent that there has been a marked consistency in egg laying during the three seasons. Both table II and plate I show quite clearly that most of the eggs are laid between the second and twelfth inch of egg gallery, and that beyond the thirteenth inch very few eggs are laid. Thus an egg gallery from 10 to 12 inches long represents the optimum in efficient construction because it contains the maximum number of eggs with the least amount of gallery. Plate I does not quite conform to the data shown in table II because the 1938 data change the curves so slightly that the plate used in the 1937 report is repeated here, and does not contain the 1938 data.

One female beetle, therefore, making one attack is capable of producing

50 young, and the new beetles having a sex ratio of .5, that is, an equal number of males and females, will provide an increase of 1 to 25 if no mortality results. This, however, does not take into consideration the second attacks made by the parent beetles, which is the next subject for discussion.

Parent Adult Emergence

It has been shown by caging experiments that the mountain pine beetle makes two attacks during the season, that is, the beetles emerge from the tree in which they made their first attack and make a second attack in another tree. The holes which these beetles make in emerging from the tree of initial attack have been termed parent adult emergence holes, and their abundance in any one tree naturally depends upon the number of beetles making first attacks. When the preponderance of attacks are made by parent beetles, parent emergence holes will be few; however, when the majority of attacks are made by new adult beetles, parent emergence holes will be abundant. Table III gives some indication of this by comparing the average number of parent emergence holes with the average number of attacks for the three attack periods.

TABLE III

Att. period:	Early		Midseason		Late	
Year	Attacks: no.	Par. emerg.: no.	Attacks: no.	Par. emerg. no.	Attacks: no.	Par. emerg. no.
1935	6.8	6.3	9.4	5.5	8.8	3.7
1936	3.0	1.8	4.0	2.5	2.0	0.8
1937	2.9	3.5	3.6	3.9	4.7	2.6

In table III the 1935 data show that the number of parent emergence holes is almost equal to the number of attacks in the early-attacked trees, slightly more than half the number of attacks in the midseason trees, and less than half in trees attacked late in the season. This is explained by the fact that the attacks in the early trees are made mainly by overwintering new adults, so that when these emerge the number of emergence holes is practically equal to the number of attacks. In the midseason trees the attacks are made in about equal numbers by new adults from overwintering trees and parent adults from the early attacks. Hence, as the new adults are the only ones to emerge, the parent emergence holes are about half the number of attacks. The late attacks are made principally by emerging parents from the midseason attacks and thus there are but few parent emergence holes compared with the number of attacks.

The same is true of the 1936 trees except that the parent emergence holes in the early trees are much less abundant. This may be explained by the fact that there was a greater number of overwintering parent beetles from the previous season, or by the fact that owing to the lesser number of attacks and continued favorable conditions within the tree many of the beetles may have deposited all of their eggs in one tree.

In the 1937 trees it is noted that parent emergence holes exceed the number of attacks in the early trees, are equal to attacks in the midseason trees, and are approximately only half the number of attacks in the late trees. Caging experiments and log examinations have shown

that in some instances parent emergence holes are more numerous than attacks, owing to the emergence of a large number of males which make separate holes. This, however, was never found as commonly as indicated by the early 1937 trees, and I am inclined to believe that some brood emergence holes were confused with parent emergence, or that some attacks were overlooked by the samplers.

Many theories have been advanced concerning the cause of parent adult emergence. It has been thought that overcrowding may cause a higher percentage of the parents to emerge because of insufficient room to complete galleries. Table IV shows the abundance of parent emergence holes according to the number of attacks.

TABLE IV
ABUNDANCE OF PARENT EMERGENCE BASED ON ATTACKS

Year	Attacks per square foot								
	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15&18	28&36
1935	2.1	3.4	5.1	6.2	7.0	7.1	6.7	7.5	5.6
1936	0.9	2.7	3.1	3.9	3.8	2.3			
1937	2.5	4.9	5.0		5.8				
Avr. 3 years	1.6	3.6	5.7	5.9	6.8	6.7	6.7	7.5	5.6

Table IV shows two main facts, (1) that there was decidedly less parent emergence from the 1936 trees and (2) that parent emergence increases with the number of attacks only up to a certain point beyond which the number of emergence holes is fairly constant regardless of the number of attacks. This indicates that the density of attack has but little influence upon the number of emerging beetles.

Another theory advances the thought that under the influence of higher temperature parent beetles complete one gallery rapidly and, finding bark conditions unfavorable for further egg laying, leave the tree for fresher material. Table V shows the abundance of parent emergence holes on the four sides of the tree based on exposure, and table VI shows the abundance of parent emergence holes at the base of the tree as compared with the average for the tree.

TABLE V
ABUNDANCE OF PARENT EMERGENCE HOLES ACCORDING TO EXPOSURE

Exposure	North	East	South	West
Attacks	5.3	5.2	5.2	5.3
Parent emergence	4.0	3.9	3.8	3.9

TABLE VI
ABUNDANCE OF PARENT EMERGENCE ACCORDING TO HEIGHT ALONG BOLE

	5-foot sample	Tree average
Attacks	7.1	5.2
Parent emergence	5.4	3.9

In these two tables it is quite apparent that parent emergence is not greater on the warmer sides of the tree, nor is it greater in the warmer upper portions of the bole.

From available data it would appear, therefore, that parent emergence is a normal habit of the mountain pine beetle which is

influenced but little by environmental conditions. From this one may conclude that where parent emergence holes are abundant compared with the number of attacks, most of the attacks were made by new adult beetles, and that where there are few parent emergence holes most of the attacks are made by parent beetles making their second attacks.

Thus it is seen that the mountain pine beetle is potentially capable of increasing at the rate of 1 to 50 instead of 1 to 25 as would be the case if only one attack were made.

Mortality Factors

Obviously there are factors at work, the sum total of which is called environmental resistance, which prevent the potential increase from becoming actual. In table VII the mortality which occurs throughout the development of the mountain pine beetle is shown.

TABLE VII
MORTALITY TO MOUNTAIN PINE BEETLE DURING DEVELOPMENT

Developmental stage	Trees examined	Bark surface	Average per sq.ft.	Decrease to succeeding stage		Percent of total decrease
	no.	sq.ft.	no.	no.	percent	percent
Egg	46	10,030	169.9	63.7	37.5	37.5
Small larva	58	10,033	106.2	43.5	41.0	25.6
Large larvae	46	9,039	62.7	23.3	37.2	13.7
Pupa	30	5,939	39.4	13.9	35.3	8.2
New adult	38	9,475	25.5	11.4	44.7	6.7
Emergence	36	8,282	14.1			
Total	254	52,798	169.9	155.8	91.7	

It is apparent in table VII that some very effective mortality factors must be at work to reduce mountain pine beetle broods so drastically. From a potential increase of 1 to 25 (in a single attack) there has been a reduction to an actual increase of 1 to 2. The greatest mortality is suffered in the egg stage, probably as a result of predacious mites and unfavorable temperature and moisture conditions.

If any of these factors which ordinarily inhibit an increase of the beetle should change so as to be no longer effective, it would then become a favorable factor.

Favorable Factors

The use of the term "favorable factor" is probably open to question because it is the general opinion that all factors included in environmental resistance are mortality factors and that when they are at their optimum for mountain pine beetle development they are merely noneffective. This is the proper and logical viewpoint, so that in explanation, the term "favorable factor" is used here to point out those factors which have decreased in effectiveness to such an extent that they favor mountain pine beetle development.

Probably one of the most important of these factors is the availability of optimum host material, that is, a plentiful supply of low-vigor trees which will offer but little resistance to the beetle's attack. Growth is commonly used as an indicator of vigor and in table VIII the growth of infested trees is compared with that of adjacent green trees. These data are also shown graphically in plate II.

PLATE II

COMPARISON OF GROWTH RATE IN GREEN AND INFESTED TREES

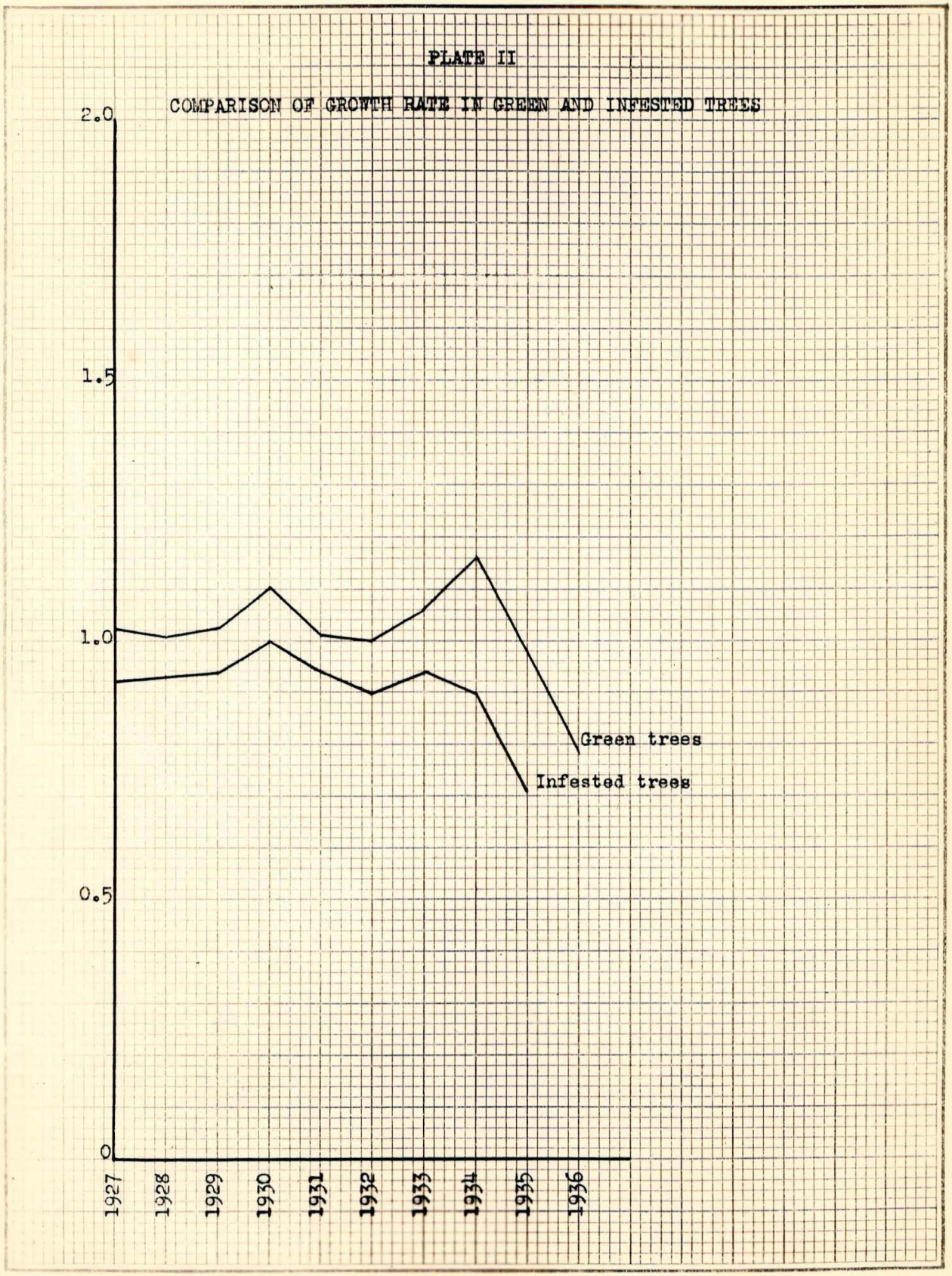


TABLE VIII

COMPARISON OF GROWTH RATE IN GREEN AND INFESTED TREES

	No. trees	Year 1936	1935	1934	1933	1932	1931	1930	1929	1928	1927	Aver. width last 10 rings	No. rings last ½ in.	No. rings last Inch
Green	131	0.78	0.98	1.16	1.06	1.00	1.01	1.11	1.03	1.01	1.02	10.2	15.6	28.6
Infested	130	0.71	0.90	0.94	0.90	0.94	1.00	0.94	0.93	0.92		9.1	19.3	32.5

Table VIII and its graphic presentation show that there is an apparent preference by the mountain pine beetle for the slower growing trees, so that if growth is an indication of vigor, then the selection is for the less vigorous trees. Plate III shows the average growth made by 66 trees for the 91 years from 1846 to 1936 inclusive. In this graph a marked decrease in growth rate with a continued downward tendency is apparent. Obviously, with such a reduction in host vigor the older white pine stands of the Coeur d'Alene National Forest are becoming more and more susceptible to attack by the mountain pine beetle. This changing growth rate has undoubtedly been caused by a number of factors such as precipitation, approaching maturity, and an increased amount of disease. Approaching maturity and disease have undoubtedly caused the general downward trend, while the minor fluctuations probably result from changes in annual precipitation.

Relative to the effect of disease, there has been an increasing amount of root rot infection throughout the forest for the past several years. Table IX shows the incidence of this disease in green and beetle infested trees, while table X shows the density of attacks and mountain beetle brood found in the diseased trees.

PLATE III

INCREMENT ON COEUR D'ALENE NATIONAL FOREST

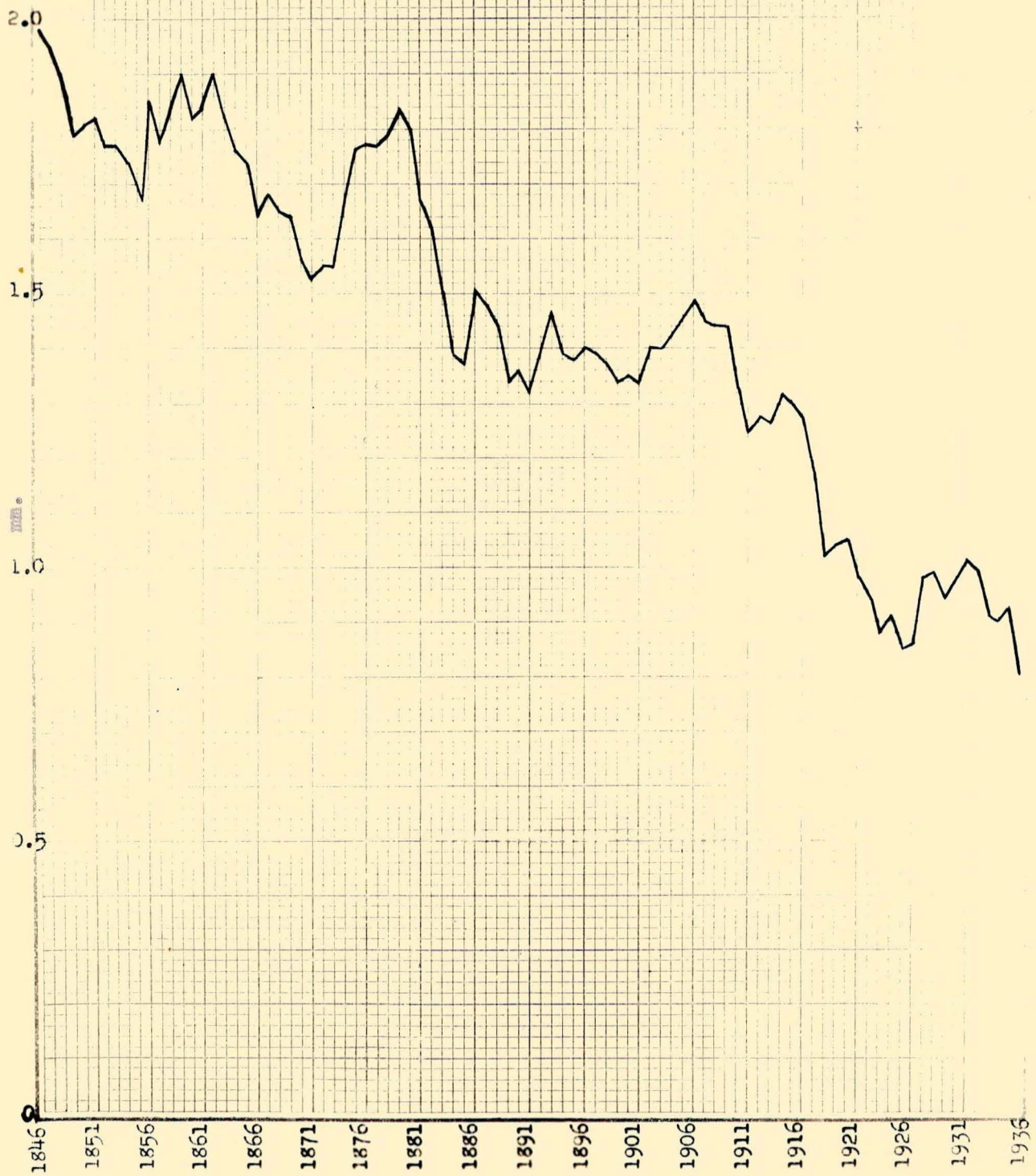


TABLE IX
INCIDENCE OF ROOT ROT INFECTION

Type tree	Root rot present		Root rot absent	
	No. trees	Percent	No. trees	Percent
Green	10	13.1	66	86.9
Infested	12	17.3	57	82.7

TABLE X
ABUNDANCE OF ATTACKS AND BROOD ACCORDING TO PERCENTAGE OF ROOT SYSTEM DESTROYED BY ROOT ROTS

Root injury	Trees examined	Attacks per square foot of bark	
		Attacks	Brood
percent	no.	no.	no.
0	35	4.4	33.1
1-50	26	3.4	21.0
51-100	30	2.0	18.6

Although there is no decided preference shown by the beetle for diseased trees, it is shown in table X that with very few attacks these trees succumb to the beetles which produce broods somewhat less in abundance than in uninfected or less severely injured trees, but which have a greater potential increase.

Thus, there is no doubt that the decreasing growth rate has given the bark beetle infestation a general tendency to increase during the past ten or twelve years. This tendency has been influenced to a great extent by actual control work and fluctuations in effectiveness of other environmental resistance factors. The effect of the more important ones will be discussed in the following section.

EFFECT OF VARIOUS FACTORS ON MOUNTAIN PINE BEETLE ABUNDANCE

Before discussing those factors which influence mountain pine beetle infestations, it might be well to repeat that it is difficult to isolate any particular one and evaluate its importance without taking cognizance of others which are effective under the same circumstances. This is more clearly shown in table XI, in which all of the important governing factors are arranged according to abundance of mountain pine beetle broods.

TABLE XI
LIMITING FACTORS ACCORDING TO BROOD ABUNDANCE

	Average brood per square foot					
	1-10	11-20	21-30	31-40	41-50	51+
Number of trees	66	30	21	10	11	24
Bark surface	11411	7732	4664	2689	2702	6219
Parasites	1.5	2.9	5.7	2.7	2.9	2.7
Predators	0.5	0.8	1.3	0.6	1.4	2.6
Robber work	38.5	23.1	18.4	23.8	11.6	12.8
No. wet site trees	3	7	3	4	6	9
No. medium site trees	17	13	6	2	2	7
No. dry site trees	44	12	12	4	3	8

It is at once apparent in table XI that no one factor, and in some cases combination of factors, can be isolated as determining mountain pine beetle population. Hence it is imperative that the interrelation of factors must be considered in discussing any one of them. Insofar

as is possible, however, each of the following factors will be considered separately with a minimum of duplication and repetition; period of attack, exposure, site, location, tree diameter, beneficial insects, bark thickness, and density of attack.

Period of Attack

To recall briefly the seasonal history of the mountain pine beetle, attacks occur throughout the insect's developmental season. There are, however, three well-defined peaks during the season, one during June, a second in late July and early August, and the third in September. These represent the three times of the year when the greatest number of attacks occur and have thus been named the early, midseason, and late periods of attack. By far the greatest number of attacks occur during the midseason period, somewhat less in the early period, and relatively few in the late period except under conditions of protracted warm fall weather.

Table XII shows the relative abundance of various factors according to the period in which the trees were attacked.

TABLE XII

ABUNDANCE OF D. M. AND ASSOCIATES IN THE THREE ATTACK PERIODS

Attack period	Early	Midseason	Late
Number of trees	82	172	41
Bark surface	16836	35062	6846
D. m. brood	18.1	22.8	28.2
Attacks	4.6	6.3	4.0
Parent emergence holes	4.1	4.3	1.7
Inches egg gallery	70.1	88.1	56.1
Parasites	4.7	3.2	2.5
Predators	2.1	1.5	1.3
Robber work	24.9	16.8	27.5

Although table XII shows that mountain pine beetle broods are most abundant in late attacks and least abundant in early attacks, it is believed that broods are approximately equal in all three attack periods. The greater parasitization in the early attacks and the slightly less advanced brood stage in the late attacks when examined would account for the inequality of brood in these two periods as compared with the midseason attacks.

As pointed out in a previous section, parent emergence holes nearly equal the number of attacks in the early trees, are more than half the number of attacks in the midseason trees, and are less than half the attacks in the late trees.

Robber work is nearly equal in the early and late trees and less in the midseason trees. There is some difference in the type of robber work, however. In the early attacks, it comprises mostly woodpecker work, while in the late attacks the bulk of robber work results from secondary bark beetles.

Parasites and predators are most abundant in the early attacks, but in general the period of attack has no great influence on abundance of mountain pine beetle brood. At least, the mortality factors at work in each group of trees are so nearly equal in effectiveness that the broods are approximately equal in the three attack periods.

Exposure

To determine the effect of exposure to the sun on abundance of the mountain pine beetle there are two things to consider, first, exposure of the terrain on which the trees grew, and second, the four exposures of the tree bole. Concerning exposure of the terrain, neither the 1935, 1936 nor 1937 trees showed any significant points when this correlation was made. This results from the fact that site moisture is of such importance as to mask any influence which exposure itself might have.

Similarly, the three seasons' data, as well as a combination of the three, failed to show that exposure of the tree bole had any important influence on abundance of mountain pine beetle brood. This

undoubtedly results from the fact that western white pine stands are well shaded, and as mountain pine beetle broods are in the lower bole, they are protected from the direct rays of the sun.

Thus in general it can be said that exposure has very little effect on mountain pine beetle infestations. However, this must not be misconstrued to mean that hot dry sites are of no importance. This fact will be discussed in the next section on site.

Site

Under this section the study has given consideration to both the site class and site moisture. Although in general more abundant mountain pine beetle broods are found in better white pine trees, site class is not a very satisfactory index of present conditions within an area because of the fact that it is based on tree height according to age, that is, a factor which was determined many years ago. For this reason, the various sites were divided according to the apparent moisture of the area. This was determined mainly by vegetation, location of the tree in relation to water, and general appearance of the site. The wet sites are close to water either in bottomland, lower slopes of ridges, or in the bottoms of small side draws. They are characterized by luxuriant growth of ground cover comprising devil's club, ferns, and gooseberry. The medium wet sites are farther removed from water about midway up the ridge as indicated by the presence of goat brush, thimbleberry, rose, black currant, and honeysuckle. The dry sites are found in openings

and on the higher slopes and ridge tops where huckleberry, rocky mountain maple, Douglas fir, bear grass, sticky laurel, and nine bark are the main indicator plants.

In table XIII the abundance of various factors is shown according to the moisture of the site on which the tree was growing.

TABLE XIII
EFFECT OF SITE MOISTURE ON ABUNDANCE

Site moisture	1937			Average 3 seasons		
	Wet	Medium	Dry	Wet	Medium	Dry
No. trees	13	22	21	67	86	143
Sq.ft. bark sur.	4162	6440	4557	15292	19434	25892
No. D. m. brood	51.9	17.5	8.0	35.7	20.6	14.9
No. attacks	5.3	3.5	1.9	6.8	6.5	4.3
No. parasites	2.6	1.9	0.5	6.0	3.3	2.4
No. predators	1.8	0.6	0.3	2.8	1.6	1.0
Sq.in. robber work	11.2	27.4	40.8	17.7	17.9	24.3

Table XIII substantiates the belief that site moisture has an important influence on abundance of various infestation factors. In spite of higher parasitization in those trees on wet sites, they produce much more numerous broods than either the medium or dry-site trees. This is also true of the medium-site trees when compared with those growing on dry sites. Broods in dry-site trees are so low as to be of very little importance. It is apparent, therefore, that site moisture has a very important effect upon mountain pine beetle infestations in western white pine, and will be discussed further under a consideration of the practical application of the study.

Location

During the course of the infestation study the data have been segregated according to the various areas or working units on the forest. This was done so as to facilitate the establishment of a biological index whereby the potentiality of an infestation could be determined. A method for predicting the future trend of an infestation will be discussed in a separate report, however, so that this section will be restricted to a consideration of the differences which exist between the various units on the Coeur d'Alene Forest.

Table XIV shows the condition of the infestation on three units just prior to emergence in 1936, 1937 and 1938.

TABLE XIV
INFESTATION ACCORDING TO UNIT

Unit	Year of attack	Trees	Bark surface	D. m. brood	Attacks	Parasites	Predators	Robber work
		no.	sq.ft.	no.	no.	no.	no.	sq.in.
Honeysuckle	1935	55	13004	6.9	9.1	2.6	2.7	13.6
	1936	31	8000	37.5	2.6	1.5	1.1	28.5
	1937	52	14255	23.1	3.4	1.7	0.8	28.3
Yellow Dog River	1935	12	2340	8.6	4.7	4.6	2.4	14.5
	1936	25	3081	19.6	2.6	9.9	0.9	21.4
	1937	2	248	66.0	4.4	5.8	1.8	2.0
Yellow Dog River Face	1935	13	2569	10.2	8.8	6.5	1.6	18.8
	1936	32	5913	23.0	2.8	3.8	1.2	18.1
	1937	2	656	28.6	4.6	0.2	0.3	5.3

The difference in character of infestation in different units is readily seen in table XIV. All of the areas showed very scarce mountain pine beetle broods in the 1935 trees with abundant parasitization.

Attacks were less numerous in the 1936 trees, but more abundant broods were produced and beneficial insects decreased except in the Yellow Dog River unit. Control work was done in both Yellow Dog areas in the fall of 1937, so that only four 1937 trees were available for examination in 1938, making the sample so small that not much dependance can be placed on the data for 1937 trees from these areas. The Honeysuckle unit, however, showed slightly less abundant broods, a slight increase in density of attack, approximately the same number of parasites and a further decrease in abundance of predators. As previously stated, these increases and decreases and their significance will be discussed in detail in a separate report considering the possibility of predicting the trend of an infestation.

Tree Diameter

In this section the effect of tree diameter on both the mountain pine beetle and beneficial insects will be discussed. Obviously the larger the tree the more infested bark surface it will contain and the greater will be the total brood produced. Hence table XV and XVI have been prepared on a square-foot basis to show the effect of the size of the tree on the various agencies.

TABLE XV

EFFECT OF TREE DIAMETER ON D. M. AND BENEFICIAL INSECTS

1937 trees

D.b.h. in in.:	6-10	11-12	13-18	19-24	25+
No. trees	2	5	22	15	12
Bark surface	172	490	4236	4974	5287
Brood	5.8	30.4	17.9	20.0	32.9
Attacks	4.3	3.3	3.0	4.0	3.4
Egg gallery	76.3	64.4	78.2	68.4	81.7
Parasites	1.8	5.1	3.3	1.2	0.5
Predators	0.1	0.7	0.8	1.0	0.8
Robber work	22.2	25.4	36.1	47.7	43.9

TABLE XVI

EFFECT OF TREE DIAMETER ON D. M. AND BENEFICIAL INSECTS

Average 1935, 1936, and 1937 trees

D.b.h. in in.:	6-10	11-12	13-18	19-24	25+
No. trees	30	43	119	74	29
Bark surface	1926	4910	21351	21096	11451
Average bark per tree	64	114	179	285	394
Brood	4.3	17.5	19.9	22.8	26.1
Attacks	5.3	5.2	5.2	6.1	5.1
Egg gallery	57.7	65.9	78.4	81.1	86.5
Parasites	4.4	8.6	4.3	2.8	0.8
Predators	0.5	1.0	1.3	1.9	2.3
Robber work	27.2	25.7	33.7	40.8	39.2

Table XVI shows that trees below 10 inches d.b.h. produce a negligible amount of mountain pine beetle brood, while trees above 10 inches produce broods in accordance with the abundance of beneficial agents, the larger trees producing the greatest number of mountain pine beetles. It is interesting to note that, in spite of nearly equal attacks, there is an increase in the amount of egg gallery from the smallest to the largest trees. This probably results from the fact that in the smaller trees the beetles are forced to groove the wood more deeply because of the thinner bark and thus excavate shorter galleries. It is apparent from these data that at the present stage of the infestation it is not necessary to treat trees under 10 inches in diameter. In fact, treatment of such trees will probably be more harmful than beneficial because of the relative abundance of parasites.

In table XVI it is seen that parasites are most abundant in 11- and 12-inch trees, while predators appear to prefer the large trees. These variations in beneficials, although apparently dependent upon tree diameter, are in reality affected by bark thickness, which in turn is influenced somewhat, but not entirely, by tree diameter. The factor of bark thickness will be discussed following the next section on the effect of beneficial insects.

Beneficial Insects

The group of insects including the parasites, predators, and

robbers should be one of the most important agencies influencing the abundance of the mountain pine beetle. Table XVII has been arranged to show the population of D. monticolae according to the parasites and predators per square foot of bark.

TABLE XVII
EFFECT OF PARASITES AND PREDATORS ON ABUNDANCE OF D. M.

Parasites and predators:	Average per square foot		
	1-10	11-20	21+
No. trees	147	11	4
Bark surface	32782	1914	721
D. m. brood	32.0	39.0	20.6
Attacks	3.4	3.4	3.3

The anticipated effect of parasites and predators on abundance of mountain pine beetle broods is not demonstrated by the data in table XVII. It is true that D. m. is not as numerous when beneficials number more than 21 per square foot, but on the other hand, no difference is shown in the first two columns of the table. This may result from the fact that there are too few trees representing the higher concentrations of parasites, or it may indicate that parasites concentrate on the more abundant broods, thus reducing them to a common level. It is also possible that because parasites and predators do not attain maximum abundance under the same conditions, and as robber work has not been included, the effect of these various factors may have masked each other.

Bark Thickness

It has already been pointed out that bark thickness has a considerable influence not only upon the mountain pine beetle but also upon the parasitic and predacious enemies of this insect. Table XVIII shows the effect of bark thickness on abundance of the mountain pine beetle and beneficial insects.

TABLE XVIII
EFFECT OF BARK THICKNESS ON ABUNDANCE

Bark thickness in inches:	0.1	0.2	0.3	0.4	0.5	0.6+
No. samples	107	233	159	153	94	91
Sq. ft. bark surface	5805	13860	9328	7979	3562	4650
No. D. m. brood	17.0	29.3	40.1	21.5	19.6	18.7
No. attacks	2.9	3.5	3.9	4.2	5.4	8.4
No. parent emergence	2.8	3.0	2.4	3.7	5.0	8.3
No. Coeloides	5.2	4.9	2.9	2.6	3.6	3.5
No. chalcids	0.1	0.4	0.6	0.6	0.3	0.6
No. predators.	0.5	1.3	1.3	1.4	2.1	6.3

It has been stated that tree diameter had an indirect influence resulting from bark thickness, and in table XVIII it is apparent that parasites prefer thin bark while predators prefer thick bark. This preference for thin bark is not true for all parasites because of the habits of the two different groups. The female Coeloides oviposits through the bark and is thus limited in oviposition to bark which is

not thicker than the length of her ovipositor, or bark in which deep cracks are present. The other two important Hymenopterous parasites, on the other hand, make use of parent emergence holes to go beneath the bark and oviposit directly on the host larvae. It is to be noticed that Coeloides is most abundant in thin bark, next in abundance in thick bark, and least abundant in bark which is medium in thickness. The surprising abundance of this parasite in the thick bark is probably caused by the deep cracks and crevices in this type of bark, thus allowing for oviposition, while the medium-thick bark is fairly smooth and too thick to be penetrated by the ovipositor.

The mountain pine beetle is decidedly most numerous in the medium-thick bark. Whether this peak in beetle abundance results from the influence of predatory or parasitic agents or whether it indicates an optimum bark thickness for mountain pine beetle development is not known. It is evident, however, that more attacks are made in the thick-barked portions of the tree, indicating that thick bark appears to be preferable to the beetle.

Bark thickness plays its most important role in limiting the height to which a tree is infested. Obviously the amount of infested bark per tree is an important element to consider in appraising the importance of any outbreak in order to determine whether the brood per tree is above or below average. Table XIX shows the bark thickness at the height of infestation as compared with tree diameter at the same point.

TABLE XIX
DIAMETER AND BARK THICKNESS AT HEIGHT OF INFESTATION

	Trees examined	Range	
		Average	Maximum	Minimum
	no.	in.	in.	in.
Bark thickness	222	0.17	0.25	0.1
Diameter	222	13.5	22.2	5.2

It is readily apparent in table XIX that bark thickness is a much more constant factor in determining infested length than is tree diameter. It has been found that although there is a wide variation in bark thickness within any one diameter class, the taper in any tree is constant depending on the height of the tree. Hence, once the bark thickness at the base of the tree and the height of the tree have been determined, the point of minimum suitable bark thickness for D. m. development can be determined.

Table XX shows the effect of both bark thickness and tree height on the infested length.

TABLE XX
INFESTED LENGTH ACCORDING TO TREE HEIGHT AND BARK THICKNESS

Tree height	Bark thickness 0.7+			0.6-0.5			0.4-0.3			0.2-0.1		
	Trees	Range	Mean	Trees	Range	Mean	Trees	Range	Mean	Trees	Range	Mean
feet	no.	ft.	ft.	no.	ft.	ft.	no.	ft.	ft.	no.	ft.	ft.
161+	7	46-130	81	5	54-100	85	18	34-122	75			
121-160	16	30-110	70	40	19-100	69	118	20-110	60	39	10-94	41
81-120	1		60	13	20-90	55	66	10-84	47	60	10-72	36
80 & under				3	20-50	36	6	25-60	43	16	10-50	24

It is seen in the preceding table that although there is an obvious correlation between infested length, and bark thickness and tree height, there is a wide range in all groupings. This results from the fact that in all groups there are to be found a few trees some of which are infested only in the basal log, while some are infested up to the very thinnest suitable bark. These trees, however, are the exception, as the widest grouping in table XX shows 15 percent of the trees to fall within 5 feet of the average, 41 percent within 10 feet of the average, 53 percent within 15 feet of the average and 66 percent within 20 feet. The best grouping shows 18 percent to fall within 5 feet of the average, 40 percent within 10 feet, 68 percent within 15 feet, and 87 percent within 20 feet. It is possible, therefore, to use bark thickness and height in determining average infested lengths, providing a sufficient number of samples are taken.

It can be said, therefore, that bark thickness is an important factor both directly and indirectly in determining the presence as well as the abundance of mountain pine beetle broods. Directly, because the beetle apparently prefers thick bark and cannot develop under bark thinner than 0.1 inch, and indirectly because bark thickness influences the abundance of beneficial insects which in turn influence the abundance of D. m.

Density of Attack

Concerning this subject, the 1935 and 1936 data showed that maximum mountain pine beetle broods were produced where there were from 9 to 14 attacks per square foot. More or less attacks were associated with a reduction in the abundance of beetle population. As there were no attacks

found in 1937 trees denser than nine per square foot, and as no fifferences were apparent in the abundance of various factors in the less dense attacks, all of the data from the 1935, 1936 and 1937 trees have been averaged together to form table XXI.

TABLE XXI
EFFECT OF DENSITY OF ATTACK ON POPULATION

No. attacks per square foot	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15&18	28&36
No. trees	101	63	47	29	27	14	8	4	2
Sq.ft. bark sur.	19718	13835	7730	5652	5188	3953	1558	717	309
No. D.m. per sq.ft.	17.0	26.0	25.8	32.3	20.6	29.6	16.3	9.0	4.7
Inches egg gallery	42.6	79.3	97.5	103.8	118.2	131.9	141.4	170.2	149.4
Gallery per attack	2&4	22,7	17.7	13.8	12.4	11.5	10.5	10.3	4.7
No. parasites	3.0	4.5	3.9	3.8	5.0	2.6	3.3	2.7	1.7
No. predators	0.9	1.4	2.3	2.0	2.9	3.7	3.4	0.4	0.3

Table XXI shows that most abundant broods are produced with a moderate number of attacks, neither dense nor scarce, but it is not possible to ascertain the exact number of attacks which is most productive. It is apparent, however, that there are three major points which enter into a consideration of this subject: (1) potential brood according to the number of eggs laid, (2) abundance of enemies, and (3) the amount of food destroyed by egg gallery construction and other agencies.

Considering the first of these, neither the number of attacks nor the total length of egg gallery are satisfactory criteria of the number

of eggs laid. It will be seen in table XXI that where there are fewer attacks there is a smaller amount of egg gallery but a decidedly greater length of egg gallery per attack. This holds true until the point is reached at which the attacks are so numerous that both the total length and length per attack must necessarily suffer a substantial reduction. In addition, it has been shown that practically all eggs are laid before the twelfth inch of egg gallery has been reached, so that any gallery over twelve inches in length does not produce much more potential brood than a gallery exactly that length. Thus it is apparent that the greatest efficiency in galler construction is secured when there are in the neighborhood of 7 to 12 attacks per square foot.

Enemies of the mountain pine beetle present a somewhat more complex situation. It will be noted in table XXI that parasites and predators appear to be most numerous in the medium-dense attacks, with parasite abundance tending toward the lighter attacks and predator abundance tending toward the heavier. This situation results, however, not from density of attack but because parasites are limited to thinner bark which is attacked by fewer beetles, while predators are usually found most abundant where maximum broods are produced. The correlation of maximum predator abundance with maximum broods results in all probability from the fact that more predators survive where food is more plentiful. It is believed that oviposition by predators is approximately equal under all conditions but that more mortality occurs where mountain pine beetle broods are less abundant due to starvation and cannibalism. It is apparent that the variation in beneficial insects shown in table XXI

is not sufficient to cause the wide difference in amount of brood, particularly because these insects are most abundant where maximum D. m. broods are found.

The amount of bark destroyed in egg gallery construction and by other agencies such as secondary bark beetles, wood borers and woodpeckers, is undoubtedly very important in this consideration. Obviously the more bark that is destroyed the less food there will be for the developing larvae. Table XXII shows these data for the 1935, 1936, and 1937 trees.

TABLE XXII
AMOUNT OF BARK DESTROYED PER SQUARE FOOT BY VARIOUS AGENTS ACCORDING TO DENSITY OF ATTACK

No. attacks	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15&18	28&36
Egg gallery	8.5*	16.8	19.5	20.7	23.6	26.4	28.3	34.0	29.9
Wood borer work	5.5	3.9	2.8	4.0	1.6	1.7	2.1	0.6	2.8
Secondary work	20.2	5.1	7.7	4.0	2.0	1.1	0.2	2.9	1.7
Woodpecker work	8.1	7.7	8.6	6.3	7.1	9.3	3.5	6.3	0.3
Total	42.3	33.5	38.6	35.0	34.3	38.5	34.1	43.8	34.7

* Expressed in square inches per square foot.

In preparing table XXII gallery construction was computed on an average width of 0.2 inch. This is slightly wider than a normal gallery, but this figure was selected to care for the wide portions of the gallery ends where feeding is done and the short lateral branches resulting from feeding by the male beetle. Woodpecker work has been included because,

where this work occurs, the bark has been completely removed and nothing but woodpecker work was counted.

Table XXII shows that although more space is utilized for gallery construction where the attacks are denser, other factors enter to make the total amount of bark destroyed approximately equal regardless of the number of attacks. These facts point to the conclusion that the potential brood indicated by the number of eggs is the criterion which determines abundance of brood. Where the attacks are of such numbers as to produce the maximum number of eggs with a minimum amount of egg gallery construction, the maximum number of individuals will reach maturity.

PRACTICAL APPLICATION OF THE STUDY

Although only three seasons have been devoted to a detailed study of mountain pine beetle infestations in western white pine, it is already apparent that additional study will yield valuable information of a practical nature. Some of the findings, however, are sufficiently definite to be of immediate use and a few of them will be discussed in this section.

One of the discoveries which will be of aid in control administration is the apparently small number of beetles which are produced from trees growing on dry sites. These scattered trees growing at higher elevations have always been a source of trouble and expense on the various control projects. They have necessitated spotting and treating on high, brush-covered ridges where working conditions are difficult and infested trees are widely scattered. It is believed that these trees need not be

treated and the cost of control will thus be considerably reduced. In conjunction with the lack of broods in trees on dry sites, the plentiful broods in trees on wet sites indicate where control will be most effective and where the work should be concentrated in the event that control funds will be exhausted prior to completing the project.

Valuable data are also being secured relative to all beneficial agencies which will enable a revision of mechanical control so that it will be on a biologically sound basis. For example, the present indications are that parasites and predators are concentrated in the smaller trees which are growing on wet sites and which have been attacked during the early attack period. In fact, all trees under 10 inches d.b.h. regardless of site contain sufficient parasites and insufficient D. m. broods to make their treatment more harmful than beneficial.

The lack of positive information has always made any consideration of slash, cull logs, and other decadent host materials a difficult task. This subject has been handled in a separate report which in brief shows that a general policy regarding this type of host material can not be made and that each situation should be considered separately.

It has long been realized that a sounder basis than number of infested trees per acre was needed to determine the various areas needful of control. Hence, one of the primary objects of the infestation study is to establish a biological index whereby the potentiality of an infestation can be determined. Such an index was proposed in 1937 and tested

during the 1938 season. This has been discussed in a separate report and it is felt that the method devised will serve the purpose for which it is intended.

SUMMARY

1. This study has for its object to study mountain pine beetle infestations in western white pine in order to obtain a better understanding of the factors that govern the behavior of these infestations. The work was begun in June 1936 and data have been gathered during the 1936, 1937 and 1938 seasons.

2. In comparing the infestation on the Coeur d'Alene National Forest during 1935, 1936 and 1937, it appears that the 1936 and 1937 trees were less densely attacked, the broods were less heavily parasitized, and that there was a more abundant emergence of D. monticolae in 1937 and 1938 than in 1936.

3. In any attack, each female beetle lays an average of 50 eggs, most of which are deposited before the 12th inch of gallery has been reached. In addition, most females emerge and make a second attack in another tree where the same egg potential results, thus making a potential of 100 eggs per female.

4. The mountain pine beetle, during development from egg to adult, suffers an average mortality of approximately 90 percent.

5. One of the factors which has favored an increase of the mountain pine beetle on the Coeur d'Alene National Forest is the loss of tree

vigor as indicated by tree growth. During the past 90 years there has been more than a 50 percent reduction in the annual increment, probably resulting from approaching maturity and disease.

6. In general, the data indicate that there is no marked difference in the number of mountain pine beetles produced from trees attacked at different times during the year.

7. The averages for all trees in all attack periods show that the mountain pine beetle and those agencies which destroy it tend to be approximately equal regardless of exposure.

8. Although the number of attacks per square foot is approximately equal on all sites and parasitization is more abundant on wet sites, there is a greater brood survival on wet sites and a greater amount of infested bark per tree, thus making a much greater total brood per tree than on dry sites. The broods produced in small trees growing on dry sites are so slight as to be negligible, particularly because these trees contain as many beneficial insects as mountain pine beetles.

9. There is considerable variation in the biological status of an infestation in the various units within its boundary.

10. Bark thickness is an important factor in mountain pine beetle infestations in western white pine. From available data it appears that the mountain pine beetle prefers thick bark as indicated by abundance of attacks and is limited in its attack to bark over 0.1 inch thick. Parasites, such as Coeloides dendroctoni, which oviposit through the bark,

are limited to bark not thicker than the length of their ovipositor except where bark cracks permit them to oviposit in thicker bark. Other parasites and predators on the other hand are more abundant in thick bark.

11. In general, parasites are most abundant in the smaller trees and upper portions of large trees which are attacked early in the season and which are growing on wet sites. Predators are most abundant in bases of large trees which are attacked early in the season and which are growing on wet sites.

12. Bark thickness apparently is the factor which governs the height to which a tree is successfully attacked.

13. The data indicate that there apparently is an optimum number of attacks per square foot of bark which produces maximum broods. Where the attacks are of such numbers as to produce the maximum number of eggs with a minimum amount of egg gallery construction, the maximum number of individuals will reach maturity.

14. A mechanical infestation determinator has been constructed from the data obtained in the infestation study, to aid in the prediction of future trends in infestations. This proved successful when tested during 1938 and will be tested further during 1939.

Respectfully submitted,

W. D. Bedard
Associate Entomologist